



Investigation of the use of Al/ZnO-NiO/p-Si/Al device produced by dynamic sol-gel spin coating technique in the detection of infrared light

*¹Ezgi Gürgeç, ¹Aydın Dikici and ²Fehmi ASLAN

¹Firat University, Technology Faculty, Energy Systems Engineering Department, Elazig, Turkey

²Rail Systems Machinery Technology, Yeşilyurt Vocational School, Turgut Özal University, Malatya, Turkey

In this study, it was investigated whether Al/ZnO-NiO/p-Si/Al photodiode devices, which we produced in our previous study and whose electrical and photoresponse properties were investigated, can be used as photodetectors in the detection of infrared light. Photoresponse properties were determined by current-voltage (I-V) and current-time (I-t) characterizations in dark and 100 mW/cm² infrared light. All devices are sensitive to infrared light. The photodetector, which is most sensitive to infrared light, is the device with a 1:1 ratio of ZnO-NiO, and the highest photosensitivity is 12979.57 in this device. The highest photosensitivity to infrared light is 8.89 x 10⁻⁴ A/W in the ZnO device. The results show that the photoresponse of photodetectors to infrared light can be controlled by changing the ZnO-NiO ratio, and Al/ZnO-NiO/p-Si/Al devices can be used as infrared light detectors.

Keywords: Nanomaterial, Opto-electronic, Infrared light, Photodetector.

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*Corresponding author: ezgigurgenc89@gmail.com

1. Introduction

Silicon (Si) based optoelectronic systems are generally preferred in Si electronic technology because of their large scale and low cost [1]. In recent years, the photoelectric and potential technical values of thin films deposited on a metal substrate have attracted a lot of attention. This is because thin films of nanostructures increase electron transfer and light absorption in optoelectronic devices. Metal oxide thin films are often preferred in photodetectors, gas sensors, solar cells and imaging systems due to their good and tunable optical, electrical and electronic properties [2,3]. Photodetectors are devices that convert visible, infrared, and ultraviolet light into electrical signals and have found use in many applications over the past few decades. These areas include optoelectronic applications such as night vision, environmental monitoring, gas sensing, fiber optic communications, biomedical imaging, and memory storage.

Photodetectors are subjects that have been extensively researched because they appeal to many different areas [2,4]. Infrared detectors have an important place among photodetectors and can detect infrared signals, which are used to detect the thermal state of the surface. For this reason, it has usage areas in aerospace, automotive, defense, medical imaging and telecommunications industries [5]. Photodetectors with very high sensitivity, quantum efficiency and light sensing properties can be produced using semiconductor materials. Semiconductors such as AlGaIn, ZnO, CdO, NiO, GaN, SiC, V₂O₅, Nb₂O₅ and TiO₂ are used in photodetector applications due to their wide band gaps. Among these semiconductors, thin films produced using GaN, AlGaIn and SiC have disadvantages such as crystal quality, cost and complex production techniques. On the other hand, the advantages of photodetectors produced using metal oxide semiconductors such as easy production, low cost, high sensitivity to light and high photoresponse attract

a lot of attention [6-8]. Nickel oxide NiO, one of the metal oxide semiconductors, is a p-type semiconductor and has a wide band gap of 3.4-4.3 eV. Also, Ni gaps and O interstitials have non-stoichiometric defects. However, it has a stable cubic structure and has weak absorption bands due to d-d band transitions. Due to these properties, NiO is a very promising semiconductor for photodetector applications [4,9]. ZnO is also an n-type semiconductor and is often preferred in many optical applications due to its superior properties. Among these properties, direct wide band gap (3.37 eV) and high exciton binding energy can be cited. Specifically, very sharp emission peaks are seen in the photoluminescent spectrum of ZnO. Such emissions have uses in opto-electronic applications such as UV photodetectors, light-emitting diodes, and UV excitonic lasers [10].

NiO and ZnO thin films can be produced a large number of techniques such as sol-gel, spray pyrolysis, sputtering, CVD, PVD and chemical bath deposition. Among these methods, the sol-gel method has advantages such as excellent composition control, allowing the production of large-scale thin films, homogeneity and low crystallization temperature [11,12].

Many researchers are investigating NiO-based p-n heterojunction devices in photodetector applications to improve the performance of photodetectors. Metal-semiconductor-metal-based photodetectors are very interesting in practice due to their simplicity, high response times, large areas and low dark currents [6]. In addition to doping, one of the methods used in changing and improving the performance of photodetectors is to create a composite structure with a different metal oxide. Thus, photodetectors with different properties can be produced [13-16].

In this study, Al/ZnO-NiO/p-Si/Al devices that we produced in our previous study were used and the use of these devices in the detection of infrared light was investigated. Photoresponse properties were determined with the FYTRONIX FY-INF1000 infrared solar simulator device.

2. Material and Method

In present study, Al/ZnO-NiO/p-Si/Al devices, the production of which has been described in detail before [17], were used and the production of these devices is briefly described in the flow chart below. (Fig. 1).

Table 1. Samples used in this study.

Sample	ZnO-NiO ratio
ZnO	1:0
NiO	1:0
3ZnO-1NiO	3:1
1ZnO-1NiO	1:1

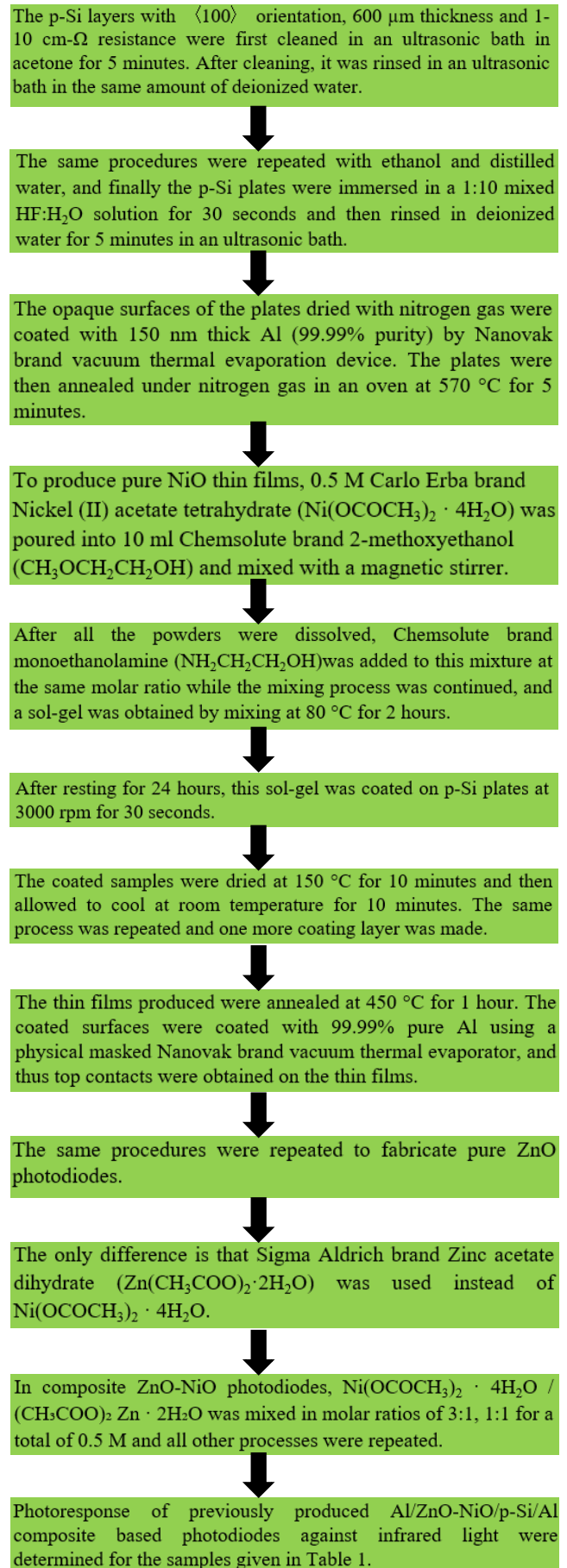


Fig.1. Flow chart.

3. Results and Discussion

Structural characterization of ZnO-NiO thin films has been explained in detail in our previous study [17]. As a result of this study, it was seen that thin films were successfully formed and thin films were composed of nanostructures. I-V characteristics were examined to find out whether the fabricated devices were responsive to infrared light. I-V properties of Al/ZnO-NiO/p-Si/Al devices in the dark and under 100 mW/cm² infrared light are shown in Fig. 2-5. In all devices, there are significant differences in currents in the negative bias region under dark and infrared light, and the current values are higher under infrared light than in dark. No significant change was observed in the forward bias region. This indicates that diodes have photocurrent properties, and diode properties have also been obtained with infrared light. In addition, all devices showed good rectification behavior [5,18,19]. As can be seen from the I-V graphs, all devices are sensitive to infrared light and their photoresponse to infrared light can be controlled by changing the ZnO-NiO ratio.

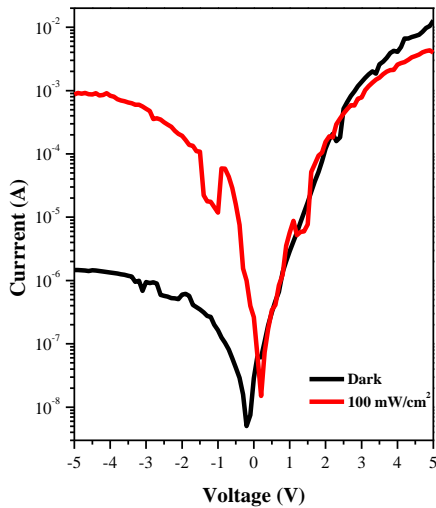


Fig.2. I-V characteristics of ZnO sample.

In order to determine the sensitivity of the devices to infrared light, the photoresponse (RR) values were calculated with the help of the equation below [20];

$$RR = \frac{I_{ph} - I_d}{I_d} \quad (1)$$

In this equation, I_{ph} and I_d represents the photocurrent and dark current, respectively. The RR values of the devices at -5V under 100 mW/cm² infrared light are 589.68, 2235.63, 1215.80 and 12979.57 for ZnO, NiO, ZnO-NiO (3:1) and ZnO-NiO (1:1) samples, respectively. The highest photoresponse value was obtained in the ZnO-NiO (1:1) composite-based device. Photosensitivity (R) values of

Al/ZnO-NiO/p-Si/Al was calculated for 100 mW/cm² infrared light intensity using the equation given in our previous study [17]. The R values of the devices are 78×10^{-4} A/W, 16.4×10^{-4} A/W, 1.52×10^{-4} A/W ve 8.89×10^{-4} A/W for ZnO, NiO, 3ZnO-1NiO and 1ZnO-1NiO samples, respectively. The highest photosensitivity to infrared light was obtained in ZnO sample. The results show that their photoresponse to infrared light can be controlled by the ZnO-NiO ratio and that Al/ZnO-NiO/p-Si/Al photodiodes can be used to detect infrared light.

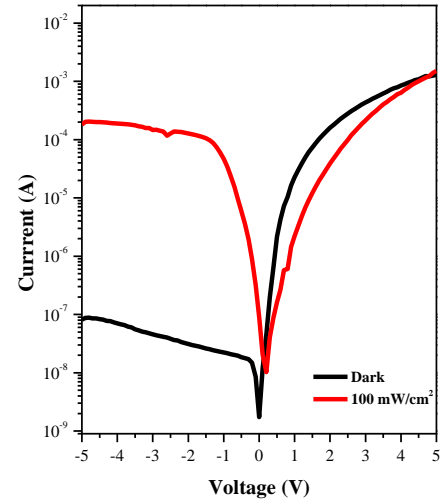


Fig. 3. I-V characteristics of NiO sample.

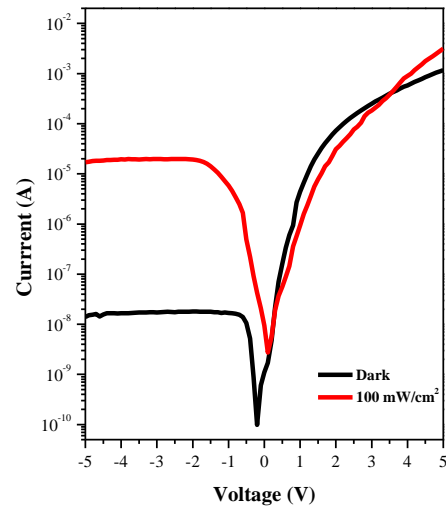


Fig. 4. I-V characteristics of 3ZnO-1NiO sample.

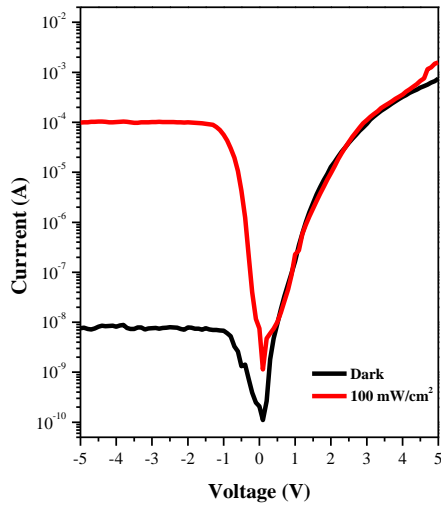


Fig. 5. I-V characteristics of 1ZnO-1NiO sample.

I-t measurements of Al/ZnO-NiO/p-Si/Al devices under 100 mW/cm² infrared light are shown in Fig. 6-9. As can be seen, the photocurrent values suddenly increased when the infrared light was turned on, and after reaching a certain saturation level, it returned to its previous level when the light was turned off. This situation repeated as the infrared light turned on and off. These results confirm that Al/ZnO-NiO/p-Si/Al photodetectors show switching behavior and photoconductive behavior according to infrared light [5,18]. The highest photocurrent value was obtained in the ZnO sample and this value is higher than the infrared photodetectors in the literature [5,18]. As a result of I-V and I-t characterizations, it has been seen that Al/ZnO-NiO/p-Si/Al diodes can be used as infrared photodetectors.

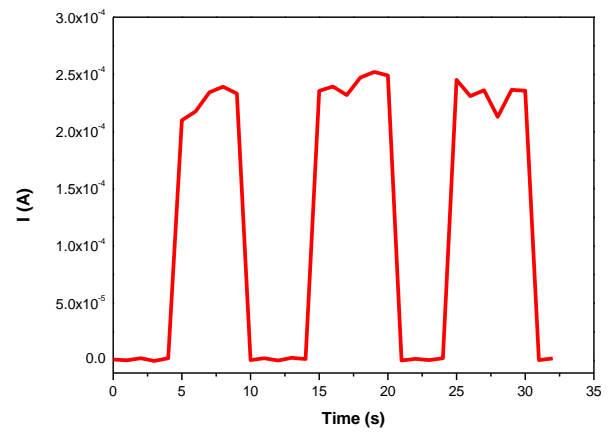


Fig. 7. I-t characteristics of NiO sample.

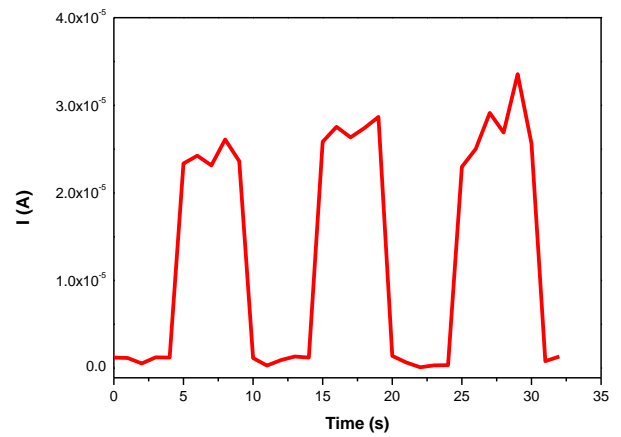


Fig. 8. I-t characteristics of 3ZnO-1NiO sample.

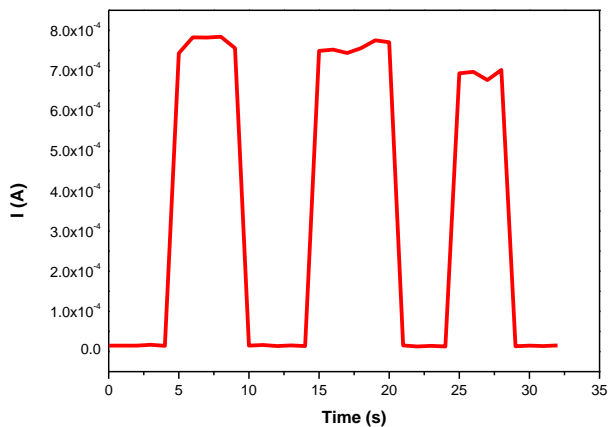


Fig. 6. I-t characteristics of ZnO sample.

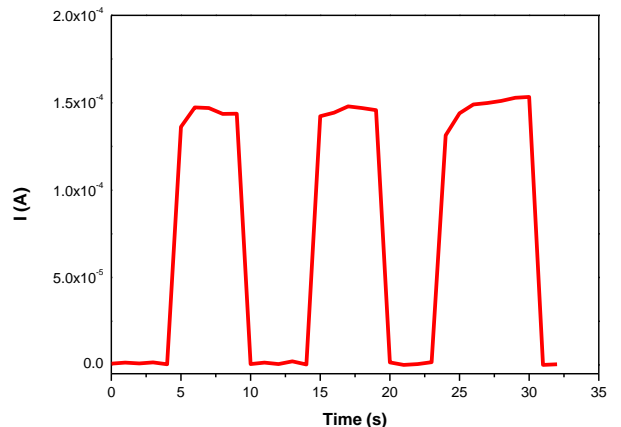


Fig. 9. I-t characteristics of 1ZnO-1NiO sample.

4. Conclusions

It has been determined that Al/ZnO-NiO/p-Si/Al devices are sensitive to infrared light and show rectification behavior. The highest photoresponse value was measured as 12979.57 in the sample with a 1:1 ratio of ZnO-NiO. The highest photosensitivity value was calculated as 8.89×10^{-4} A/W in pure ZnO sample. The photoresponse, photosensitivity and photocurrents of the devices can be controlled by changing the ZnO-NiO ratio. Different types of infrared photodetectors can be produced by changing the ZnO-NiO ratio. As a result, it was seen that produced Al/ZnO-NiO/p-Si/Al devices in our previous study can be used as photodetectors in the detection of infrared light.

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